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Performance analysis of DFIM fed by matrix converter and multi level inverter

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ABSTRACT

In this paper, we study the performance of a doubly fed induction machine when its stator and rotor are respectively fed by a matrix converter and a multi level inverter. For this, we first present the structures and models of the machine, the multi level inverter and matrix converter. Then, using simulation analysis, we proceed to test the rate of harmonic distortion of the stator currents obtained for the two considered configurations. The obtained simulation results by numerical simulations are shown and analyzed.

1. Introduction

Today, the growing interest of the doubly fed induction machine (DFIM) is due to its applications for renewable energy generator or motor for industrial applications. It offers the accessibility to its rotor and thus the possibility of a power converter as well as the side of the stator side of the rotor. Some studies make it a serious competitor to several electric machines, especially the classic squirrel machine. Indeed, in wind energy, DFIM has many advantages: the converter connected to the rotor frame is sized to a third of the rated rotor losses in the semi-conductor is low, etc. For motor applications, the induction machine occupies the first place. However, the DFIM fed by two present converters, especially for applications of great power performances, motor over speed (up to twice the rated speed) without demagnetization, good performance at very low speed operation without speed sensor, etc. In addition, DFIM with its dual power offers several possibilities for reconfiguring the operating mode of the machine.

Indirect frequency conversion using a cascade rectifier–inverter is more used than the direct conversion. It is desirable to replace the first conversion with compact converter, while maintaining good waveform input/output and the possibility of adjusting the power factor at the entrance. In recent years, research advances in power electronics have enabled the emergence of a matrix converter (MC) for converting direct AC/AC. Today, the MC has become an important research and more attractive by many researchers in the field of training or variable-speed generation with these advantages over conventional converters such as cyclo-converter the rectifier–inverter cascade. In the studies of the matrix converter, there are control strategies mainly adopted to control the matrix converter. The MC has recently been the subject of lots of research for its simple topology, possibility of greater power density due to the absence of a large DC link capacitor and easy control of the input power factor [1,2].

The first method based on Venturini modulation and the second on space vector modulation. In this paper we have used the method Least Mean Square Error (LMSE). This method has a unique advantage over others, which is reducing the total harmonic distortion reduced. In this paper, we present the modeling of DFIM and simulation results for the considered machine when it is fed with a multi-level inverter and a matrix converter.

2. Modeling of the doubly fed induction machine

The doubly fed induction machine has a three-phase winding in the stator. Its rotor consists of a three-phase winding accessible by three rings with sliding contacts (brushes) [3]. The DFIM with the distributions of its windings and its own geometry is very complex. Therefore to analyze it, its exact configuration is taken into account. It is then necessary to adopt the following simplifying assumptions in order to develop a simple model [4–6]. Then, to develop a model of DFIM, it is assumed that the machine is symmetric and constant air gap, the magnetic circuit is not saturated and it is perfectly laminated iron losses and hysteresis are negligible, the magneto motive force (mmf) created in one phase of the stator and rotor are sinusoidal distribution along the gap and the influence of the temperature effect is neglected. Thus, considering

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the schematic in Fig. 1, where the phases are designated by s_a, s_b and s_c in the stator, r_a, r_b and r_c for the rotor and the electrical angle θ defines the relative position between the instantaneous axis magnetic phase stator and rotor.

The matrix equations of the voltages of stator and rotor phases that describe its operation are defined below:

$$[U_s] = [R_s][i_s] + \frac{d}{dt}([L_s]\cdot[i_s]) + \frac{d}{dt}([M_{sr}]\cdot[i_r]) \tag{1}$$

$$[U_r] = [R_r][i_r] + \frac{d}{dt}([L_r]\cdot[i_r]) + \frac{d}{dt}([M_{sr}]\cdot[i_s]) \tag{2}$$

where:

$$[U_s] = [U_{sa} \quad U_{sb} \quad U_{sc}]^T, \quad [i_s] = [i_{sa} \quad i_{sb} \quad i_{sc}]^T \tag{3}$$

$$[U_r] = [U_{ra} \quad U_{rb} \quad U_{rc}]^T, \quad [i] = [i_{ra} \quad i_{rb} \quad i_{rc}]^T \tag{4}$$

$$[R_s] = \begin{bmatrix} R_S & 0 & 0 \\ 0 & R_S & 0 \\ 0 & 0 & R_S \end{bmatrix} \quad \text{and} \quad [R_r] = \begin{bmatrix} R_r & 0 & 0 \\ 0 & R_r & 0 \\ 0 & 0 & R_r \end{bmatrix} \tag{5}$$

$$[L_s] = \begin{bmatrix} l_S & M_s & M_s \\ M_s & l_S & M_s \\ M_s & M_s & l_S \end{bmatrix} \quad \text{and} \quad [L_r] = \begin{bmatrix} l_r & M_r & M_r \\ M_r & l_r & M_r \\ M_r & M_r & l_r \end{bmatrix} \tag{6}$$

$$[M_{sr}] = \begin{bmatrix} M_{sr}\cdot\cos\theta & M_{sr.}\cdot\cos\left(\theta+\frac{2\pi}{3}\right) & M_{sr.}\cdot\cos\left(\theta-\frac{2\pi}{3}\right) \\ M_{sr.}\cdot\cos\left(\theta-\frac{2\pi}{3}\right) & M_{sr}\cdot\cos\theta & M_{sr.}\cdot\cos\left(\theta+\frac{2\pi}{3}\right) \\ M_{sr.}\cdot\cos\left(\theta+\frac{2\pi}{3}\right) & M_{sr.}\cdot\cos\left(\theta-\frac{2\pi}{3}\right) & M_{sr}\cdot\cos\theta \end{bmatrix} \tag{7}$$

$$[M_{sr}] = [M_{sr}]^T \tag{8}$$

The electrical equations and the flux linkage expressions of the DFIM in the synchronous reference frame (d_q) are given by:

$$\begin{cases} V_{ds} = R_s\cdot i_{ds} + \frac{d\phi_{ds}}{dt} - \omega_e\cdot\phi_{qs} \\ V_{qs} = R_s\cdot i_{qs} + \frac{d\phi_{qs}}{dt} - \omega_e\cdot\phi_d s \\ V_{dr} = R_s\cdot i_{dr} + \frac{d\phi_{dr}}{dt} - \omega_{sl}\cdot\phi_{qr} \\ V_{qr} = R_r\cdot i_{qr} + \frac{d\phi_{qr}}{dt} - \omega_{sl}\cdot\phi_{dr} \end{cases} \tag{9}$$

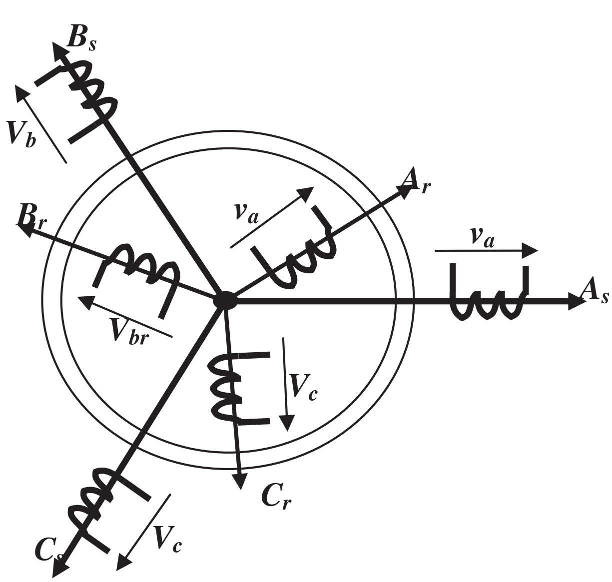

Fig. 1. Schematic representation of DFIM.

$$\begin{cases} \phi_{ds} = L_s\cdot i_{ds} + M\cdot i_{dr} \\ \phi_{dr} = L_s\cdot i_{ds} + L\cdot i_{dr} \\ \phi_{qs} = L_s\cdot i_{qs} + M\cdot i_{qr} \\ \phi_{qr} = L_s\cdot i_{qs} + L_r\cdot i_{qr} \end{cases} \tag{10}$$

With V_{ds}, i_{ds}, Φ_{ds} are respectively the «d» components of the stator voltages, current and flux linkage; V_{qs}, i_{qs}, Φ_{qs} are respectively the «q» components of the stator voltages, current and flux linkage; V_{dr}, i_{dr}, Φ_{dr} are respectively the «d» components of the rotor voltages, current and flux linkage; V_{qr}, i_{qr}, Φ_{qr} are respectively the «q» components of the rotor voltages, current and flux linkage; R_s and R_r are respectively the per phase stator and the per phase rotor resistance; w_e is the speed of the synchronous reference frame; L_s, L_r, M are respectively the stator self inductance and the rotor self inductance and the mutual inductance between stator and rotor.

The electromagnetic torque is evaluated as:

$$T_{em} = p\cdot M(i_{qs}\cdot i_{dr} - i_{ds}\cdot i_{qr}) \tag{11}$$

With p is the number of pole pairs.

The dynamical equation of machine is described as:

$$J\frac{d\Omega}{dt} = T_{em} - T_l - k_f\Omega \tag{12}$$

After arrangement, we obtain a repository related fields turning [7], the global model of the DFIM is presented by the following expression (13):

$$\begin{cases} \frac{di_{ds}}{dt} = A_{11}\cdot i_{ds} + A_{12}\cdot i_{qs} + A_{13}\cdot i_{dr} + A_{14}\cdot\omega_r\cdot i_{qr} + B_{11}\cdot V_{ds} + B_{12}V_{dr} \\ \frac{di_{qs}}{dt} = -A_{12}\cdot i_{ds} + A_{11}\cdot i_{qs} - A_{14}\cdot\omega_r\cdot i_{dr} + A_{13}\cdot i_{qr} + B_{11}\cdot V_{qs} + B_{12}V_{dr} \\ \frac{di_{dr}}{dt} = A_{31}\cdot i_{ds} + A_{32}\cdot\omega_r\cdot i_{qs} + A_{33}\cdot i_{dr} + A_{34}\cdot\cdot i_{qr} + B_{31}\cdot V_{ds} + B_{32}V_{dr} \\ \frac{di_{qr}}{dt} = -A_{32}\cdot\omega_r\cdot i_{ds} + A_{31}\cdot i_{qs} - A_{34}\cdot i_{dr} + A_{33}\cdot i_{qr} + B_{31}\cdot V_{qs} + B_{12}V_{qr} \\ \frac{d\omega_r}{dt} = \frac{p^2\cdot M}{J}(i_{dr}\cdot i_{qs} - i_{qr}\cdot i_{ds}) - \frac{k_f}{J}\cdot\omega_r - \frac{p}{J}\cdot T_l \end{cases} \tag{13}$$

where,

$$A_{11} = -\frac{1}{\sigma\cdot T_s};\quad A_{12} = \left(\frac{1-\sigma}{\sigma}\cdot\omega_r + \omega_s\right);\quad A_{13} = \frac{M}{\sigma L_s T_r};\quad A_{14} = \frac{M}{\sigma\cdot L_s};$$

$$A_{31} = \frac{M}{\sigma L_s T_s};\quad A_{32} = -\frac{M}{\sigma\cdot L_s};\quad A_{33} = -\frac{1}{\sigma\cdot T_r};\quad A_{34} = \left(\omega_s - \frac{\omega_r}{\sigma}\cdot\right);$$

$$B_{11} = \frac{1}{\sigma\cdot L_s};\quad B_{12} = -\frac{M}{\sigma L_s L_r};\quad B_{31} = -\frac{M}{\sigma L_s L_r};\quad B_{32} = \frac{1}{\sigma\cdot L_r}.$$

3. Modeling and control of the inverter

3.1. Structure of NPC three level inverter

Fig. 2 shows the structure of a three-phase three level inverter. The DC voltage source is formed by the series connection of two groups of capacitors provides at point (0) a half-voltage $E/2$.

This structure outputs three voltage levels $-E/2$, 0, and $E/2$ according to the configurations defined in Table 1.

The three-level inverter output voltages are obtained using the following expression [8]:

$$U_{io} = C_i\cdot E/2 \tag{14}$$

With, $C_i = -1$; $C_i = 0$ or $C_i = 1$;

$$\begin{bmatrix} U_{an} \\ U_{bn} \\ U_{cn} \end{bmatrix} = 1/6\begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix}\cdot\begin{bmatrix} U_{ao} \\ U_{bo} \\ U_{co} \end{bmatrix} \tag{15}$$

Now if you consider all the switches, all phases, we obtain $8^3 = 64$ possible combinations [9], where the 27 combinations presented in Table 2 are used practically.